**Closure to “Severe Damage of a Pile Group due to Slope Failure” by D.E.L. Ong,
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The authors thank the discussor V. Diyaljee, for his interest in their research publication. To recap, this paper examines the pre-failure and post-failure behaviour of an instrumented cast-in-place concrete pile group comprising four 900-mm diameter piles subject to soil movements as a result of a slope failure that occurred during the unexpected early arrival of a rain storm prior to the year-end monsoon. Out of the four piles, two piles were instrumented. The front pile was instrumented with strain gauges only, while the rear pile was instrumented with both strain gauges and in-pile inclinometer. In-soil inclinometer that measured the free-field soil movement was installed about 1.5 m away from the pile group (see Fig. 1). Because the soil slip was not anticipated in the pile design, only nominal 0.5 % steel reinforcement was provided in the piles and this translates to an ultimate bending moment capacity of only 520 kNm. In comparison, the ultimate bending moment capacity for a 1075-mm diameter bored pile with 3 % steel reinforcement used by Chandrasekaran et al. (1999) was about 3000 kNm as additional bending moment due to soil movement had been anticipated.

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30 Diyaljee (2015) recommended that the authors provide further details and
31 clarification on some specific discrete events and their associated construction
32 sequence so that the overall construction methodology and timeline are more
33 accurately represented. The recommendations suggested by Diyaljee are reasonable
34 and appropriate in view that forensic engineering often requires reporting of explicit
35 details during more critical events. Therefore, the detailed information as
36 recommended by Diyaljee (2015) will be provided hereinafter.

37 The key events as shown in Fig. 5 of Ong et al. (2015) will now be further
38 elaborated to reflect the associated discrete events that also took place within the
39 specific construction periods. Immediately, after the occurrence of soil slip on Day 0
40 (Stage 1), canvas sheet was placed over the affected area to prevent further infiltration
41 of rainwater. During Stage 2 construction, the failed slope was reinstated on Day 4 by
42 placing imported sand onto the failed slope surface to stabilize the affected area. From
43 Day 5 to Day 6, a stretch of about 25 m of sheet pile wall was installed at the toe of
44 the failed slope area and its immediate vicinity in an attempt to negate further slope
45 movements. Further excavation of 1 m was carried out uphill and behind the installed
46 sheet pile wall on Day 7, thus exposing the installed cantilever sheet pile wall.
47 Unfortunately, soil movements continued to occur unabatedly as observed by the
48 increasingly tilted cantilever sheet pile wall as shown in Fig. 2 and also as recorded by
49 the adjacent in-soil inclinometer as shown in Fig. 7 of Ong et al. (2015) until Day 62,
50 despite the installation of waling and strutting system on Day 19 to brace the
51 cantilever wall. Fig. 3 shows the improved representation of the construction timeline
52 to reflect more of the discrete construction activities that had taken place in between
53 the successive major events for better clarity.

Besides the general comments, Diyaljee (2015) also requested for specific information that could provide valuable insights to develop understanding of the behavior of piles in relation to the type of cracking so as to improve the analysis and design of piles subject to soil movements. These specific comments are described henceforth:

1. All the cast-in-place piles within and outside of the boundary of slope excavation were installed before the initial slope failure. However, the localized excavation to expose the pile heads and subsequently casting of the pile caps, was carried out at different times. For example, the strip of pile groups in the western boundary at Gridline 1 with elevation of RL103.20 m (including the instrumented pile group), was the first area to be locally excavated and casted with pile caps. This was followed by the successful capping of the pile groups located along Gridlines 3 and 4 at elevation of RL100.55 m.

Finally, when the installed pile groups at Gridlines 2 and the installed single piles between Gridlines 2 and 3, all at elevation of RL98.0 m (to support the proposed underground water tank) were to be exposed during the subsequent excavation works, slope failure occurred overnight (Day 0) due to the unforeseen heavy rain storm. When the slope failure occurred, the excavation depth was 3.5 m as measured from the existing ground level and was just 1.7 m shy of the proposed final excavation level.

2. The locations of the piles supporting the underground water storage tank and sheet piles in relation to the boundary of the slope excavation are now re-emphasized in Fig. 1 for greater clarity.

78 3. From Fig. 2, it was indeed noted that further excavation of 1 m uphill of the
79 reinstated slope and behind the installed sheet pile wall did induce additional
80 soil movements as recorded by both the in-pile and in-soil inclinometers
81 located adjacent to the failed slope in Ong et al. (2015).

82 4. The sheet piles were installed on Day 5 and Day 6 at the toe of the failed slope
83 area and its immediate vicinity in an attempt to stabilize the affected area and
84 to minimise further slope movements (see Fig. 2). However, on Day 7 (end of
85 Stage 2), subsequent excavation of 1 m that was carried out uphill and behind
86 the installed sheet pile wall inevitably caused further detrimental soil
87 movements perhaps due to limited mobilization of the remolded shear strength
88 of the failed clay slope in trying to sustain the original slope gradient.

89 5. As addressed in point 1 above, the cast-in-place piles supporting the
90 underground storage tank were installed before the soil slip occurred on Day 0.

91 The authors agree with Diyaljee (2015) that the observational and numerical
92 backanalysis performed herein are indeed useful to develop insights for the proper
93 understanding and appropriate design of pile reinforcement in (a) cast-in-place
94 retaining walls supporting deep basement excavations (Ong et al., 2006, 2009 &
95 2011) and Leung et al., 2006) or walls located adjacent to existing structures and (b)
96 landslide stabilizing passive piles (Chow, 1996 & Maugeri et al., 1994). Other
97 geotechnical scenarios where the concept of soil-structure interaction involving the
98 detrimental effect of soil movements can be of relevance include pile-supported
99 bridge abutments (Stewart et al., 1994a & 1994b, Springman, et al., 1991) and
100 possibly riverine infrastructure located in riverbanks subject to large daily tidal
101 fluctuations (Ting & Tan, 1997, Ting, 2004 and Wong et al., 2015), which is being
102 investigated and shall be discussed in future papers.

Besides the fundamental understanding of soil-structure interaction, the authors would also like to acknowledge the importance of accurate assessment of the soil undrained shear strength during pile design. Ong et al. (2006) and Leung et al. (2006) have detailed the importance of differentiating the use of pre-excavation or post-excavation undrained shear strength in assessing the effect of soil movement on piles especially when large strain deformations are expected. As in most practical cases, the pre-excavation undrained shear strength values are available only. Therefore, the maximum normalized limiting soil pressure/undrained shear strength ratio, p_y/c_u of 6 was used in the backanalysis, based on the recommendation of Leung et al. (2006).

The soil limiting pressure, p_y , which is defined as the maximum soil pressure that can act on a pile without causing any further increase in pile bending moment, becomes more important during large strain soil deformations. In this case study, a 'soil flow' phenomenon most likely occurred during the slope failure, whereby the soft marine clay would just flow around the instrumented piles once limiting soil pressure had been reached. Another important design parameter worth mentioning is the soil moderation factor applied to the free-field soil movements recorded by the in-soil inclinometer, which was located adjacent the failed slope. Leung et al. (2006) and Ong et al. (2009) suggested a soil moderation factor of 0.7 for the case of a 4-pile group to reflect the phenomenon of soil reinforcing and shadowing effects due to the presence of multiple individual piles within the group.

Since the numerical backanalysis in Ong et al. (2015) yields reasonably good agreement with the field measured results that consider the appropriate use of the cracked pile properties, the practical application of the concept of limiting soil pressure based on p_y/c_u ratio of 6 and the appropriate use of soil moderation factor have now been successfully validated by this case study.

In conclusion, the reasonably close agreement of backanalysis results can be attributed to the following important contributions:

1. The quality workmanship in preparing and connecting all the geotechnical instruments to the data logging unit that involved a lot of painstaking, but worthwhile efforts. Calibrating, commissioning and maintaining the instrumentation system also formed part of the challenges in this study.
2. Discipline in maintaining a daily site monitoring log book system and photographic evidences to keep track on the construction sequence and methodology, which formed an indispensable formal record for the forensic engineering endeavour. The discrete construction events as highlighted by Diyaljee (2015) are as important to create a seamless integration of important technical information.
3. Fundamental understanding of the key parameters relevant to this study that include the concept of soil limiting pressure, soil moderation factor and progressive cracking of pile that affects its response when subject to soil movements.

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Fig 1

Fig 2

Fig 3

Stage	Day	Key Event	Construction Sequence
1	Day 0	<ul style="list-style-type: none"> Soil slip occurred Excavation depth at 3.5 m 	<p>The diagram shows a cross-section of a slope with a 1V:2.5H ratio. A soil slip is indicated by a dashed line and an arrow. An 'Instrumented pile group' is shown on the left. To the right, 'Piles to support underground storage tank' are shown. The excavation depth is 3.5m.</p>
2	Days 1-7	<ul style="list-style-type: none"> Day 4: Reinstatement of failed slope Days 5-6: Sheet pile installation Day 7: Further excavation to 4.5m depth Further soil movement occurred 	<p>The diagram shows the 'Reinstated slope' with a dashed line. A 'Sheet pile' is installed. Arrows indicate 'Soil movement due to excavation of slope'. The excavation depth is 4.5m.</p>
3	Days 8-14	<ul style="list-style-type: none"> Localized excavation to expose installed pile (heads) supporting underground storage tank 	<p>The diagram shows 'Excavation to expose installed pile heads'. Arrows indicate 'Further soil movement'.</p>
4	Days 15-18	<ul style="list-style-type: none"> Further excavation to 5.0m depth 	<p>The diagram shows 'Further Excavation 5.0m'. Arrows indicate 'Further soil movement'.</p>
5	Days 19-21	<ul style="list-style-type: none"> Days 19-20: Temporary waling & strutting system installed Day 21: Further excavation to 5.5m depth 	<p>The diagram shows 'Further excavation 5.5m'. Arrows indicate 'Further soil movement'. 'Temporary struts installed' are shown on the right.</p>
6	Days 22-29	<ul style="list-style-type: none"> Further excavation to 6.0m depth 	<p>The diagram shows 'Further excavation 6.0m'. Arrows indicate 'Further soil movement'.</p>
7	Days 30-62	<ul style="list-style-type: none"> Casting of pile caps & further works 	<p>The diagram shows 'Casting of pile caps & further works'. Arrows indicate 'Further soil movement'.</p>
8	Day 63	<ul style="list-style-type: none"> Backfilling works 	<p>The diagram shows 'Backfilling works' with a dashed line indicating the backfill area.</p>

LIST OF FIGURES

Fig. 1. Plan view showing the locations of instruments, instrumented pile group and piles supporting the underground storage water tank at the site

Fig. 2. Sheet piles installed on Days 5 & 6 at toe of the failed slope and subsequently tilted

Fig. 3. Timeline and details of excavation works